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Basic Design Study of RFQ for Helium Implantation in Power Semiconductors

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1. Introduction

An efficient method to make a power semiconductor is the implantation of the helium ions into the basis material. The cyclotron is commonly used to obtain the accelerated helium beams. However the beam current is limited up to few μA and it takes too long time in the irradiation process. Because a promising alternative accelerating structure is the RFQ (radio frequency quadrupole) for higher beam current, we studied the RFQ to accelerate helium ions of 1.0 mA up to 3 MeV for the power semiconductor production. We choose the resonant frequency and beam duty of 200MHz and 2% by considering the length of RFQ and the cooling problem. The frequency will be controlled by a low level RF system to compensate the frequency shift due to the cooling temperature variation. This work summarized the basic design study for the helium RFQ

2. Beam Dynamics Study

We used the RFQ design codes for the basic design and the beam dynamics study [1]. The design requirement is summarized in Table 1. The RFQ parameters for beam dynamics simulation are given in Fig. 1. The final modulation is 1.8 and the focusing efficiency is 5.1. The synchronous phase is -30° and the vane voltage is 85 kV. We found that the peak surface electic field is less than 1.69 Kilpatrick (Fig. 2).

Table 1. RFQ design requirement.

Parameters	Values
Reference Particles	$^4He^{2+}$
Frequency	200 MHz
Input Energy	10 keV/u (40 keV)
Output Energy	750 keV/u (3MeV)
Beam Current	1 mA
Beam Duty	2%
Kilpatrick	< 1.8

Table 2. RFQ beam parameters (PARMTEQM result).

Energy	3.06 MeV
Transmission Rate	97.8%
Input Emittance (rms)	0.2 mm-mrad
Output Emittance (rms, transv.)	0.2 mm-mrad
Output Emittance (rms, long.)	0.27 deg-MeV

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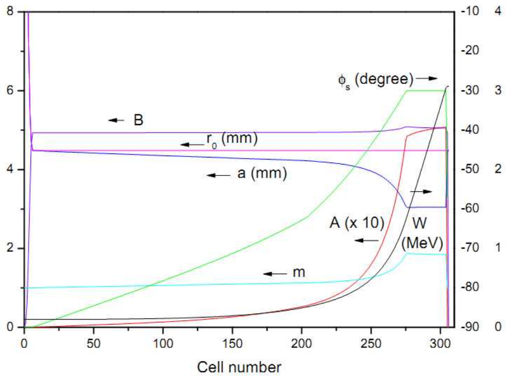

Fig. 1. RFQ parameters depending on cell numbers (m: modulation, ϕ_s: synchronous phase, a: minimum aperture radius, r_0: average aperture radius, A: acceleration efficiency, B: focusing efficiency, W: kinetic energy) .

The configuration plot of the beam through the RFQ is given in Fig. 3. We found that the transmission rate is 97.8% and the energy spread is ±0.1 MeV. Fig 4 shows the output beam in x-x', y-y', x-y, and Δϕ-ΔE phase spaces. We obtained that the total length of RFQ is 2.95 m. The required rf power is estimated to 130 kW by the simulation. The RFQ beam properties are summarized in Table 2.

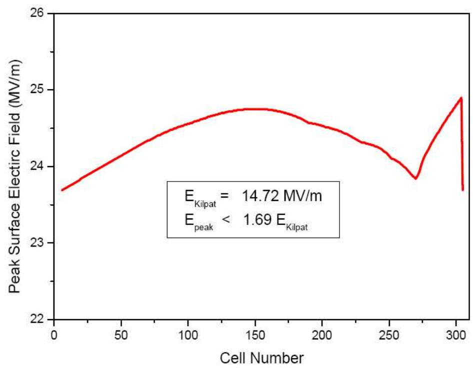

Fig. 2. Peak surface electric field.

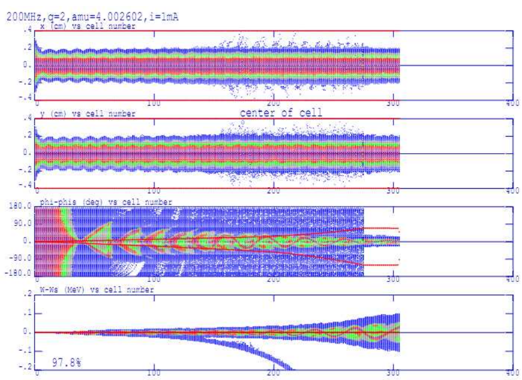

Fig. 3. Configuration plots of beams in RFQ.

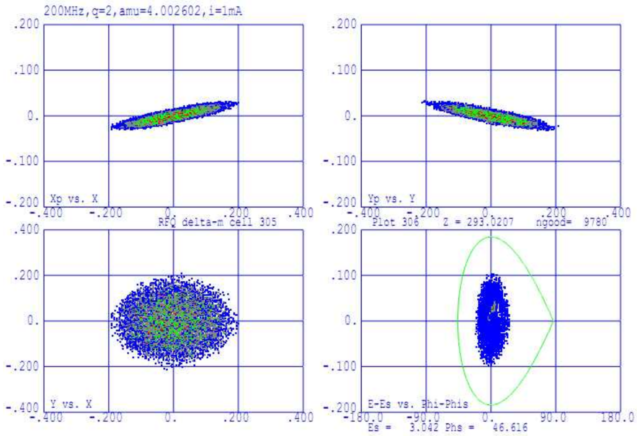

Fig. 4. RFQ output beam in phase spaces.

3. RF System Configuration

The required RF power is 130kW in the simulation. The specification of the high power RF system is 200kW by considering the 20% shunt impedance degradation, 10% transmission loss and 10% control margin. Two possible candidates for the high power RF amplifier are tetrode and solid state amplifier. The tetrode based amplifier system can be configured with cascade system with three stages and has an advantage of widely used system for a long time. The solid state amplifier based system can be configured with the parallel connection of the 200W grade unit module. The advantage of the solid state amplifier system is its low operation voltage whereas the price is still expensive. Fig. 5 is an example of a RF system for the RFQ.

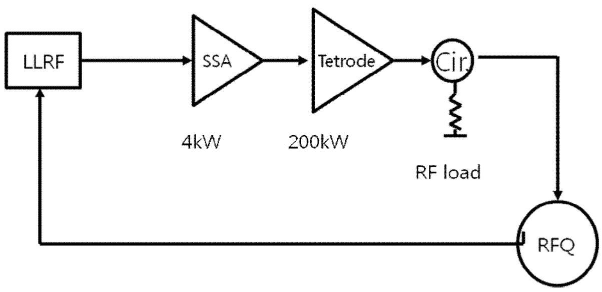

Fig. 5. RF system for the case of a tetrode amplifier.

The system consists of single RFQ cavity. Therefore it is easier to change the driving frequency following the cavity frequency than to keep the cavity frequency constant, because cavity resonant frequency control systems such as movable tuners or temperature controlled cooling system are required to keep the cavity constant. The low level RF system to control the RF frequency and amplitude is planned by using the FPGA based digital control technology. The commercially available digital board such as PENTEK7142 has its ADC, DAC channel and FPGA with internal DDS, clock functions [2]. By comparing the pickup signal with the reference signal, the error signal can be used to change the driving frequency by using the internal DDS. The PI control logics are implemented in the FPGA to control the DDS and RF amplitude

4. Conclusions

We have studied and designed a RFQ as a He accelerator for implantation on power semiconductors. In this study, we found that it is simple and compact with a RF system and can supply high current He beam enough for semiconductor production. The feasibility study with detail designs will be done.

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